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PRACTICAL ASPECTS OF DESIGN FOR HURRICANE-RESISTANT STRUCTURES; WIND LOADINGS

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INTRODUCTION

In designing structures to resist hurricanes in most of South Florida, practical and relatively economic sets of standards have evolved. There is wide adherence to these hurricane-resistant standards in the metropolitan areas of South Florida with a combined population of over four million permanent residents. Public opinion in this area has accepted the need for these standards.

Basic design storm used in the building code in South Florida is a 120 miles per hour hurricane, at 30 feet elevation above grade. This corresponds to a Category 3 Hurricane on the Saffir-Simpson Hurricane Scale (111-130 mph wind velocity). A 1/7th power increase in velocity with increase in height is used. In a historical review of hurricanes during this century, 21 hurricanes equalling or exceeding Category 3 on the Saffir-Simpson Hurricane Scale, struck the Florida coast.

Outstanding features of hurricane resistant standards in use in this area are detailed requirements for the use of various materials of construction. The building code in use will not prevent damage for a Category 4 or Category 5 Hurricane but should reduce the effects of these catastrophic storms.

With a consideration of construction to resist the effects of tropical storms now being given increasing emphasis in many parts of the world, details of hurricane-conscious South Florida procedures are of value.

BASIC DESIGN STORM USED IN SOUTH FLORIDA

Basic design storm used in the South Florida area is a 120 miles per hour velocity storm as measured at a height of 30 ft. above grade. Wind velocity increase with respect to height is based on the relationship of $(H/H_{30})^{1/7}$. Basic design velocity pressure is $q_z = 0.00256\ V^2$ and varies from a velocity pressure at 30 ft. above grade, of 36.9 pounds per sq. ft., to a velocity pressure of 88.8 pounds per sq. ft. at 650 ft. above grade.

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The design storm frequency is based on an expected 50 year period of recurrence. The design storm was based on relatively meagre past statistical data available for the Florida area.

The basic design storm and resultant velocity pressures for exposed coastal areas of South Florida are somewhat less than in the method of calculating velocity pressures given in the proposed American National Standard Institute A58.1 Standard, entitled "Minimum Design Loads for Buildings and Other Structures" proposed for revision but not yet adopted (1982). The ANSI Standard establishes "importance factors" depending on building occupancy, type of structure and the location of the structure with respect to the coast line, and based on use of a special exposure "D" for flat unobstructed coastal areas. The South Florida Building Code is uniform and does not consider location of a structure with respect to the ocean line, does not consider gust response factors, and applies uniformly to all areas where it is in use in South Florida, even those areas as much as 20 miles back from the coast-line

Under the proposed ANSI code the basic design storm at 33 ft. above grade gives a velocity pressure of 38.2 psf. This gives fairly good correlation to the 30 ft. high design velocity pressure in the South Florida Building Code of 36.9 psf.

The author established a hurricane scale in 1971 in a report on hurricanes he prepared for the United Nations, entitled "Low Cost Construction Resistant to Earthquakes and Hurricanes". Categories given were tied into a subjective scale based on varying amounts of structural damage ranging from a broken light of glass to an entire building failure. To show damage potential, the summary of the scale is reproduced here, without the complete structural scale definitions:

DEFINITION OF THE SAFFIR/SIMPSON SCALE

SCALE NUMBER (CATEGORY)	DESCRIPTION (See structural scale)	WIND (MPH) VELOCITY	POSSIBLE TIDAL SURGE (Ft.)* above sea level	EXAMPLES IN FLORIDA
1	MINIMAL	74-95	4-5	AGNES 1972
2	MODERATE	96-110	6-8	CLEO 1964
3	EXTENSIVE	111-130	9-12	BETSY 1965
4	EXTREME	131-155	13-18	DONNA 1960
5	CATASTROPHIC	GREATER THAN 155	GREATER THAN 18	1935 STORM ON FLORIDA KEYS

* Surge may not be concurrent with maximum wind velocity

The scale is used extensively by the National Weather Service to provide a continuing assessment of the damage potential for wind and storm-surge from a hurricane.

BUILDING CODES

The South Florida Building Code was adopted in Dade County, Florida in 1957 and has been in use as an area-wide code by the almost four million permanent population of the South Florida area. The code is primarily a specification-type code and describes in detail material requirements, methods of assembly, size and spacing of connection members, size and strength of supporting members where structural engineering analysis is not performed etc., etc. The code does permit some of the leeway permitted in a performance-type code and does contain certain performance criteria. In the sections covering wind loadings the code permits the building official to accept a design whose validity is based upon wind tunnel data.

The origin of the code was with the Uniform Building Code of the International Conference of Building Officials (at that time called the Pacific Coast Building Officials Conference). The South Florida Building Code diverged from the Uniform Building Code and is much more rigorous in those areas where the use of concrete masonry and reinforced concrete predominate and where hurricane-resistant requirements are important for safety. The code is the only hurricane-resistant building code in use in the U. S. that emphasizes hurricane-resistant design and construction. Codes in other parts of the U. S. do not stress the requirements for hurricane-resistant design and construction, although such codes as the Standard Building Code do now give some loadings for hurricane prone areas.

The code in general attempts to strike a practical and realistic median between the requirements for rigid hurricane-resistant standards and the practical aspects of construction economics. In a consideration of detailed requirements, attention must be given to the economic factors of construction since it would be possible to make construction requirements so rigorous that it would be impossible to construct one-story residences, for example.

The proposed ANSI Code A58.1 (revision) is an advisory document; it will <u>not</u> constitute a legal building code or legal standard but will be used only for advisory purposes. Various countries adopt a legal nation-wide standard for building code requirements, loadings, etc. In the U.S.A., however, adoption of building requirements is a function of local government; although there are three regional building codes (the so-called "Model" codes) in use throughout many general regions of the U.S.A., most of the larger cities have adopted their own specific building code, or have modified the model codes.

The ANSI A58.1 Code uses a basic 110 mph fastest-mile speed for the South Florida area and uses a basic 100 mph fastest-mile speed for the Texas Gulf coast, and Alabama and Mississippi Gulf coast. The reduction in speed

for the Gulf Coast may be somewhat low.

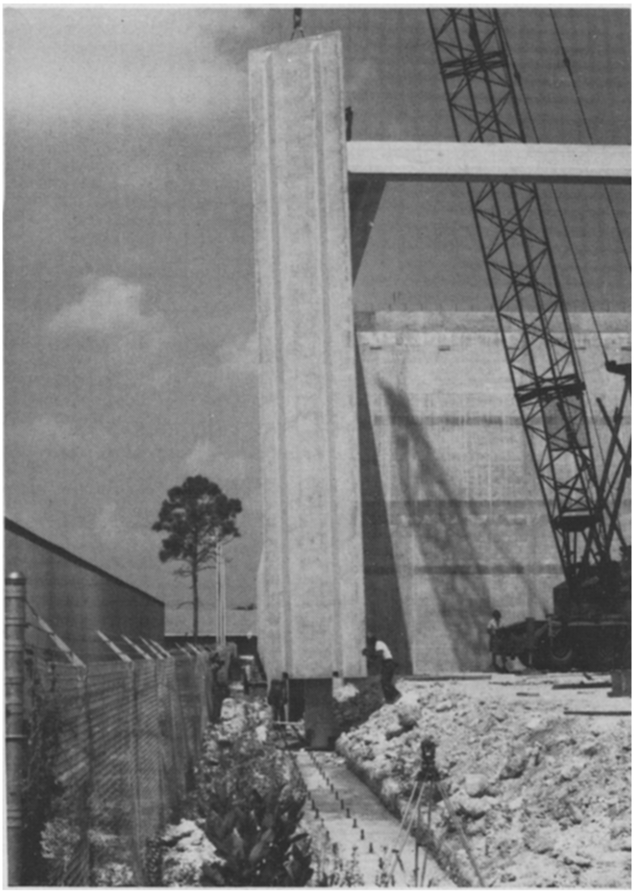

Figure 1 45 ft. high prestressed concrete load-bearing wall section being erected. Note anchorage.

DETAILED SPECIFICATIONS GIVEN IN BUILDING CODE

Detailed specification requirements are given in the South Florida Building Code for all construction materials.

In general, the type of construction most used in the South Florida area is essentially a concrete block masonry type of construction; the area is distinctive for this type of construction which has been in use since development began about 60 years ago.

Concrete Block Masonry Type of Construction

The chapters in the building code covering reinforced concrete and prestressed concrete generally conform to standard methods of design and construction for concrete in use throughout the U.S.A. (American Concrete Institute Standard 318).

The chapter on Masonry is the distinctive chapter in the code that covers specific requirements for concrete block masonry. (The standard masonry wall in use in this area is constructed of a nominal 8" thick hollow concrete block (7 5/8" x 7 5/8" x 15 5/8") Standard Unit of hollow Concrete Block, conforming to the Standard Specifications for Hollow Load Bearing Concrete Masonry Units, ASTM C-90).

The most distinctive feature for the wall panels requires that the wall panel area between reinforced concrete beams and reinforced concrete tie columns cannot exceed 256 sq. ft.

These are specific requirements for concrete block walls:

Reinforced Concrete Tie Columns

Concrete tie columns are required in all exterior walls of unit masonry except in one-story buildings of residential occupancy. Concrete tie columns are required at all corners, at intervals not to exceed 20 feet center-to-center spacing between columns, adjacent to any corner opening exceeding four feet in width, adjacent to any wall opening exceeding nine feet in width, and at the ends of free-standing walls exceeding two feet in length. Structurally designed columns may be substituted for the tie columns specified in the code.

In one-story residential buildings, the reinforced concrete (bond) tie beams are anchored at intervals not to exceed 20 feet center-to-center to the foundation or floor slab, if required to resist uplift forces required by the code. This anchorage provides the equivalent strength of a vertical 5/8" steel reinforcing bar bent into the foundation or floor slab and into the tie beam, encased in concrete or mortar, and lapped a minimum of 18 inches. Alternate methods of providing anchorage may be used where design computations are furnished and approved by the Building Official. Tie columns are not less than 12 inches in width, with an unbraced height of not over 15 ft. The tie columns are reinforced with not less than four 5/8" steel vertical bars for 8" x 12" columns, and not less than four 3/4" steel vertical bars for 12" x 12" columns nor less reinforcing steel than 0.01 of the cross-sectional area for columns of other dimensions, nor less than may be required to resist computed axial loads or bending forces.

The spacing of concrete columns for skeleton frame construction, may exceed these specified spacings provided the masonry panels have an area of less than 256 square feet and the structural system is designed to transmit

horizontal wind loads to the columns.

Tie Beams (Horizontal Bond Beams)

Tie beams of reinforced concrete are placed in all walls of unit masonry, at each floor or roof level, and at such intermediate levels as are required to limit the vertical heights of the masonry units to 16 feet.

All tie beams have a width of not less than a nominal eight inches, have a height of not less than 12 inches and are reinforced with not less than four 5/8" steel reinforcing bars placed two in the top and two in the bottom of the beam.

Tie beams are continuous. Continuity is provided at corners by bending two bars from each direction around the corner for a distance of 18 inches. Continuity at columns is provided by continuing horizontal reinforcing through columns or by bending horizontal reinforcing in the columns a distance of 18 inches into the horizontal tie beams.

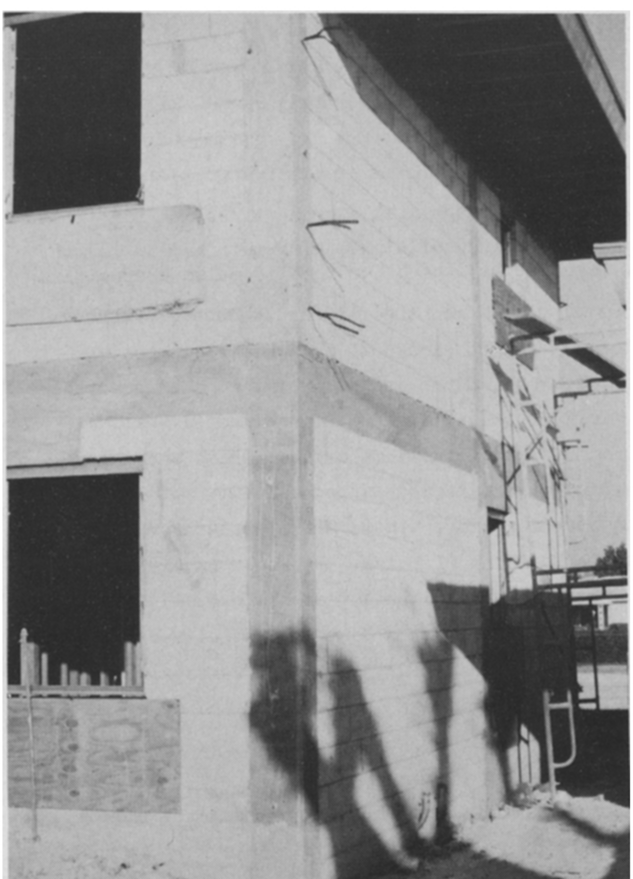

Figure 2. Typical tie beam and tie column construction with masonry infill.

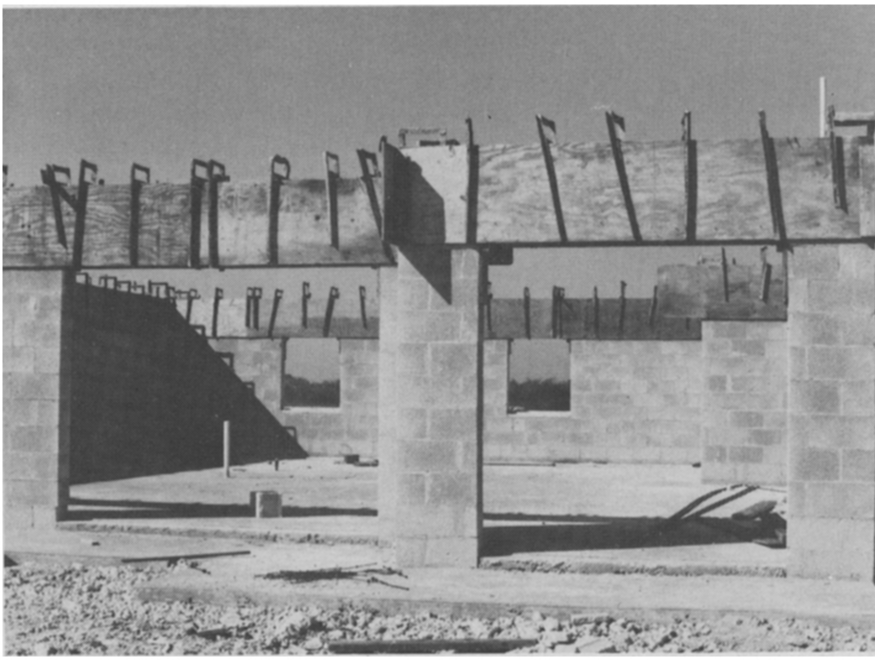

Figure 3. Forms for tie beam, under construction.

Foundations

The code specifies standard design and construction requirements for footings. For all structures a continuous reinforced concrete footing is required under all walls, as specified in the code for one or two story buildings, and consisting of continuous reinforced concrete footings from 10" by 16" in dimension to 12" by 36", based on the allowable soil bearing capacities for the location. The continuous footing is reinforced with two or three 5/8" steel reinforcing bars lapped and continued around footing corners, so that great lateral strength is provided for the structure. These requirements apply to all structures, including one-story residences. For taller structures or for those with heavier foundation loads, design must be by competent structural engineers.

Pile foundations require a design by a competent structural engineer. Piling must be adequately tied to the superstructure above, through grade beams or pile caps, so that the necessary strength is provided for uplift loads or lateral loads where these are critical items in the design.

Steel;Timber

Steel and timber, in general, require that all members be designed by methods of rational analysis, by competent structural engineers. Design standards conform to the generally accepted standards for these materials in use through the U.S.A. Timber design load tables are provided so that joist and rafter spacing and size may be utilized by table for one and two story buildings, unless otherwise modified by a competent structural engineer.

In a consideration of steel design and timber design, special consideration is given to anchorage details and tie-down details, in the code. The light weight of these materials, as compared to reinforced concrete, makes it mandatory to give careful thought to these criteria. For example, in the steel rigid frame type of industrial building, special consideration must be given to the uplift loads and lateral loads brought to the foundation by the rigid frame. Uplift in this type of low dead load to live load ratio building will generally be far in excess of the dead load of the building itself.

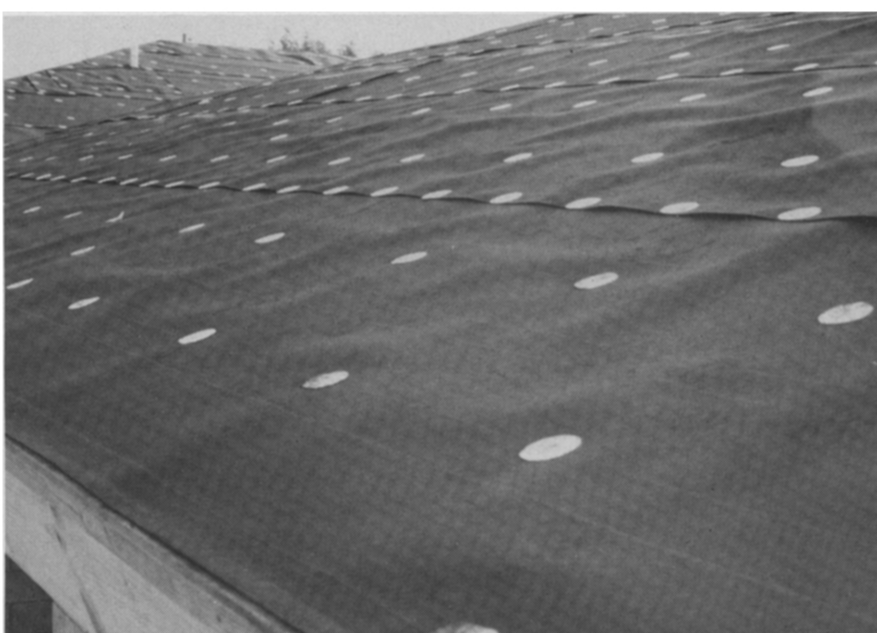

Figure 4. Note nailing for roofing membrane to resist uplift loads.

Cladding and Glazing

Specific and detailed requirements are given in the code for the design, testing and inspection of glazing and curtainwall. These items are of the highest importance in insuring that a hurricane-resistant building is provided since a failure of windows or curtainwall may cause gutting of the contents of the structure, may endanger the inhabitants of the structure and can introduce very high positive wind loads in the structure which will cause the roof to fail.

Since glass has been used so extensively for high-rise construction in place of masonry, this is a critical material. Glass design for exterior walls is based either on engineering analysis, test, or reference to tables of permissible areas, based on four-side support for heights up to 750 ft. above grade. The thicknesses and areas specified in the table (not reproduced in this paper) are in conformance with code requirements and are based on allowable working stresses varying from 4,000 to 8,000 psi, depending on the thickness of the glass.

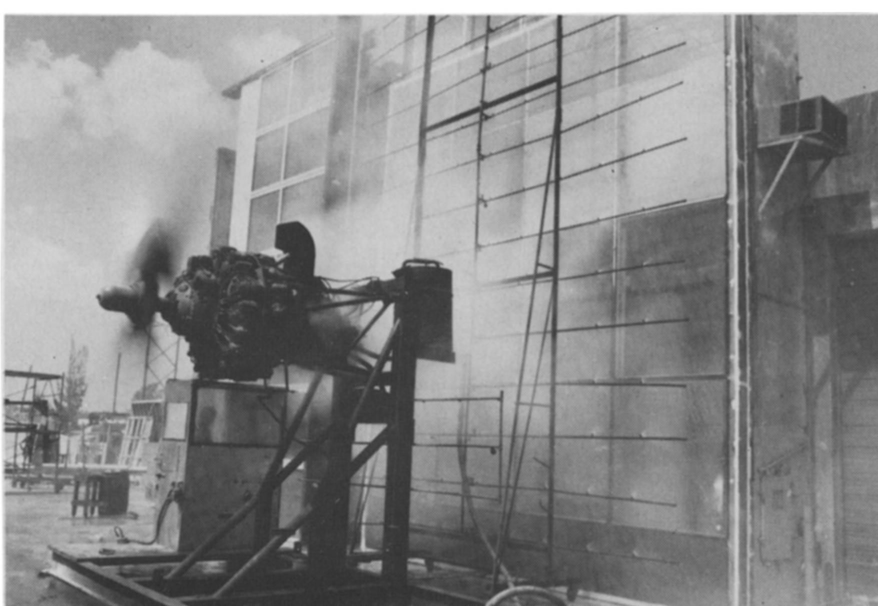

Figure 5. **Dynamic test of curtainwall.**

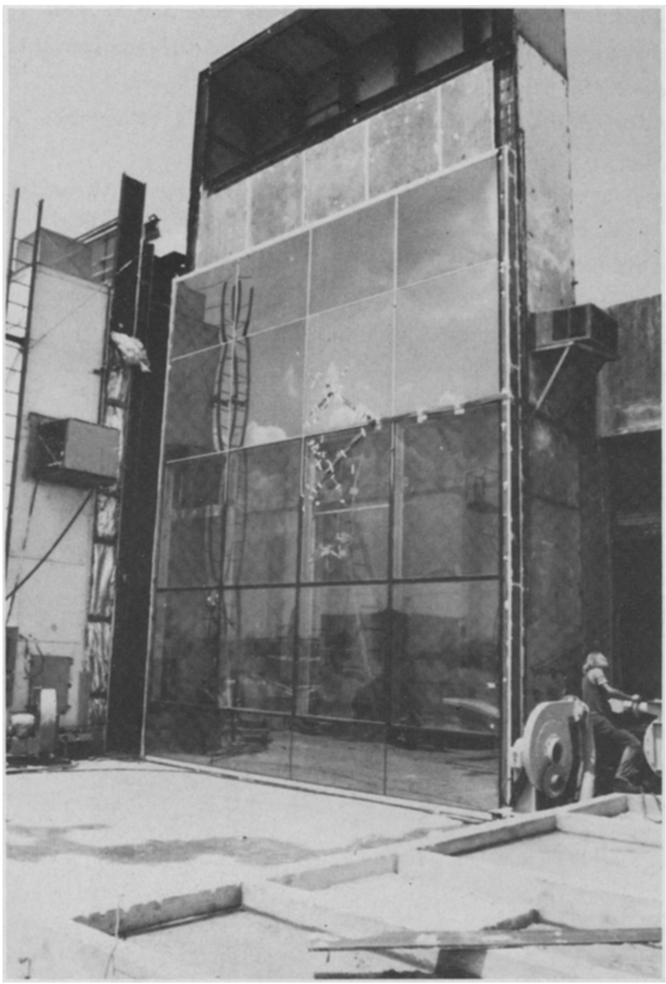

Figure 6. **Vacuum chamber test of curtainwall. Note strain gages.**

Code Enforcement

Without any system of inspections to enforce the code requirements after a building permit is issued, there is no way of determining if the work in the field was accomplished in accordance with the approved plans and building code requirements.

Inspection practices in force in the South Florida area may vary substantially but they can be classified into two types of inspections:

(a) called-for inspections where the contractors or sub-contractors call at some particular phase and ask for an inspection;(b) discretionary inspections by an inspector made at any point in the progress of the work at the discretion of the inspector.

The code lists in detail various mandatory inspections, indicated as follows, for various building stages:

Foundation Inspection	Lathing Inspection
Pile Inspection	Plumbing Inspection
Reinforcing Steel Inspection	Electrical Inspection
Frame Inspection	Store Front Inspection
Roofing Inspection	Window and Glass Door Inspection
Curtainwall Inspection	

The structure must be approved at each stage in construction.

Figure 7. High-rise reinforced concrete frame under construction.

Figure 8. High-rise reinforced concrete frame under construction.

Figure 9. Tornado in South Florida area March 7, 1982 with wind velocity high enough to deposit heavy steel boat trailer on roof of residence. Residence damage confined to roofing and roof structure; building structure essentially undamaged.

CONCLUSION

With a consideration of construction to resist the effects of tropical storms now being emphasized throughout the U.S.A. and throughout the world, some of the details of South Florida procedures may be of value.

A properly designed building code must be followed, based on the adoption of a design hurricane of either Category 3 or Category 4 under the Saffir-Simpson Scale. The code must, because of practical considerations, be a specification-type code and must have specific procedures for design for the various construction materials used.

An administrative system of product approval for building components must be established. A properly designed high-rise or medium rise building - as a result of glass and cladding failures - may end up with a completely gutted interior if insufficient attention has been given to those important architectural components making up the exterior cladding.

Code enforcement and inspection are the final steps. Without enforcement and inspections, the finest building code or finest set of specifications and standards is not of much value.

It is emphasized that there is a long chain of actions and attentions to details that must be accomplished by the building owner, the architect, the structural engineer employed by the architect for the actual structural design, the building official, the building contractor, the building contractor's suppliers, and the resident architect or resident engineer. None of the links in this chain can be neglected, to insure a hurricane-resistant structure.

REFERENCES:

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